News from the electroweak SM Fit and Constraints of SM Extensions

SM4 and Single-top Workshop
Leinsweiler

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27th March 2012

Outline

- News from the electroweak SM Fit (e.g. Higgs searches, M_W, α_s)
- Comparison of indirect and direct determination of Higgs mass
- Tests of the electroweak SM
- Results for the STU parameters
- Parameter constraints for fourth generation and littlest Higgs model
- Summary

Experimental Measurements

- Z-pole observables including their correlations: LEP/SLD experiments
  [ADLO+SLD, Phys. Rept. 427, 257 (2006)]
- new W mass measurements from D0 and CDF combined with LEP result: M_W = 80.385 ± 0.015 GeV
  [ADLO, hep-ex/0612034][D0,arXiv:1203.0293][CDF, arXiv:1203.0275][LEPEWWG]
- Γ_W: LEP/Tevatron
  [ADLO, hep-ex/0612034][CDF&D0, arXiv:0908.1374]
- $\overline{m}_c$, $\overline{m}_b$: world averages
  [PDG, J.Phys.G G37 (2010)]
- m_t: Tevatron using 5.8 fb^{-1}
  [D0&CDF, arXiv:1107.5255]
- **$\Delta\alpha_{had}^{(5)}(M_Z^2)$:** including α_S dependency (rescaling)
  [Davier et al. EPJ C71 (2011)]
- direct Higgs mass exclusions (at 95% CL):
  - **LEP: M_H > 114 GeV**
    [ADLO: Phys. Lett. B565, 61 (2003)]
  - **Tevatron: 100 – 119 GeV and 141 – 184 GeV**
    [TEVNPH: arXiv:1203.3782]
  - **ATLAS: 110 – 117.5 GeV, 118.5 – 122.5 GeV, and 129 – 539 GeV**
    [ATLAS-CONF-2012-019]
  - **CMS: 127.5 – 600 GeV**
    [CMS-PAS-HIG-12-008]
  - **LHC+Tevatron: excess at 125 GeV**

	Parameter	Input value
LEP	M_Z [GeV]	91.1875 ± 0.0021
LEP	Γ_Z [GeV]	2.4952 ± 0.0023
LEP	$\sigma^0_{\rm had}$ [nb]	41.540 ± 0.037
LEP	R^0_ℓ	20.767 ± 0.025
LEP	$A^{0,\ell}_{\rm FB}$	0.0171 ± 0.0010
LEP / SLD	A_ℓ $^{(\star)}$	0.1499 ± 0.0018
SLD	A_c	0.670 ± 0.027
SLD	A_b	0.923 ± 0.020
LEP	$A^{0,c}_{\rm FB}$	0.0707 ± 0.0035
LEP	$A^{0,b}_{\rm FB}$	0.0992 ± 0.0016
LEP / SLD	R^0_c	0.1721 ± 0.0030
LEP / SLD	R^0_b	0.21629 ± 0.00066
LEP	$\sin^2\theta^\ell_{\rm eff}(Q_{\rm FB})$	0.2324 ± 0.0012
	M_H [GeV] $^{(\circ)}$	–
	M_W [GeV]	80.385 ± 0.015
	Γ_W [GeV]	2.085 ± 0.042
	$\overline{m}_c$ [GeV]	$1.27^{+0.07}_{-0.11}$
	$\overline{m}_b$ [GeV]	$4.20^{+0.17}_{-0.07}$
	m_t [GeV]	173.3 ± 1.1
	$\Delta\alpha^{(5)}_{\rm had}(M_Z^2)$ $^{(\dagger\triangle)}$	2757 ± 10
	$\alpha_s(M_Z^2)$	–
	$\delta_{\rm th} M_W$ [MeV]	$[-4, 4]_{\rm theo}$
	$\delta_{\rm th} \sin^2\theta^\ell_{\rm eff}$ $^{(\dagger)}$	$[-4.7, 4.7]_{\rm theo}$
	$\delta_{\rm th}\rho^f_Z$ $^{(\dagger)}$	$[-2, 2]_{\rm theo}$
	$\delta_{\rm th}\kappa^f_Z$ $^{(\dagger)}$	$[-2, 2]_{\rm theo}$

† in units of 10^{-5}

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- direct Higgs mass exclusions (at 95% CL):

Still allowed regions:
117.5 GeV < M_H < 118.5 GeV
122.5 GeV < M_H < 127.5 GeV

  - **LHC+Tevatron: excess at 125 GeV**

LEP
SLD

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Theoretical Input

- electroweak precision observables expressed as functions of the free SM parameters: M_Z, M_H, m_t, $\Delta\alpha_{had}^{(5)}(M_Z^2)$, $\alpha_S(M_Z^2)$, $\overline{m}_c$, $\overline{m}_b$
- most important predictions for constraining the Higgs mass
  - M_W and $\sin^2\theta^f_{eff}$: full two-loop + leading beyond-two-loop correction
    [M. Awramik et al., Phys. Rev D69, 053006 (2004)][M. Awramik et al., JHEP 11, 048 (2006), M. Awramik et al., Nucl.Phys.B813:174-187 (2009)]
  - theoretical uncertainties (due to *eg.* truncation of higher QCD orders): M_W (δM_W=4 MeV) and $\sin^2\theta^f_{eff}$ ($\delta\sin^2\theta^l_{eff}$ =4.7 $\cdot 10^{-5}$)
  - $\sin^2\theta^f_{eff}$ defines asymmetry parameter and forward-backward asymmetry
- partial Z widths (or ratio of them) important for determination of α_S
  - Z couplings implemented by parametrization (one-loop level and partly at two-loop level for $\mathcal{O}(\alpha\alpha_s)$)
    [Hagiwara et al., arXiv:1104.1769)]
    correction applied for large Higgs masses (M_H>500 GeV) to account for difference between ZFitter and parametrization
    [Bardin et al, CPC 133,299(2001)][Arbuzov et al., CPC 174,728(2006)]
  - radiator functions describe final QCD and QED radiation,
    [Hagiwara et al, Z.Phys. C64, 559 (1994), Bardin et al. ,The standard model in the making (1999), Bardin et al., CPC. 133, 229 (2001)]
    including N^3lO to hadronic Z decay (new!!!)
    [P.A. Baikov et al., Phys. Rev. Lett. 101 (2008) 012022, P.A. Baikov et al., arXiv:1201.5804 [hep-ph]]
- width of W boson not crucial for fit due to large experimental uncertainty
  [Hagiwara et al., arXiv:1104.1769)]

Determination of Strong Coupling

R_l (ratio of hadronic and leptonic Z width) most sensitive to α_s

N^3LO determination of α_S:

$$\alpha_s(M_Z^2) = 0.1192 \pm 0.0028$$
$$\pm 0.0001$$

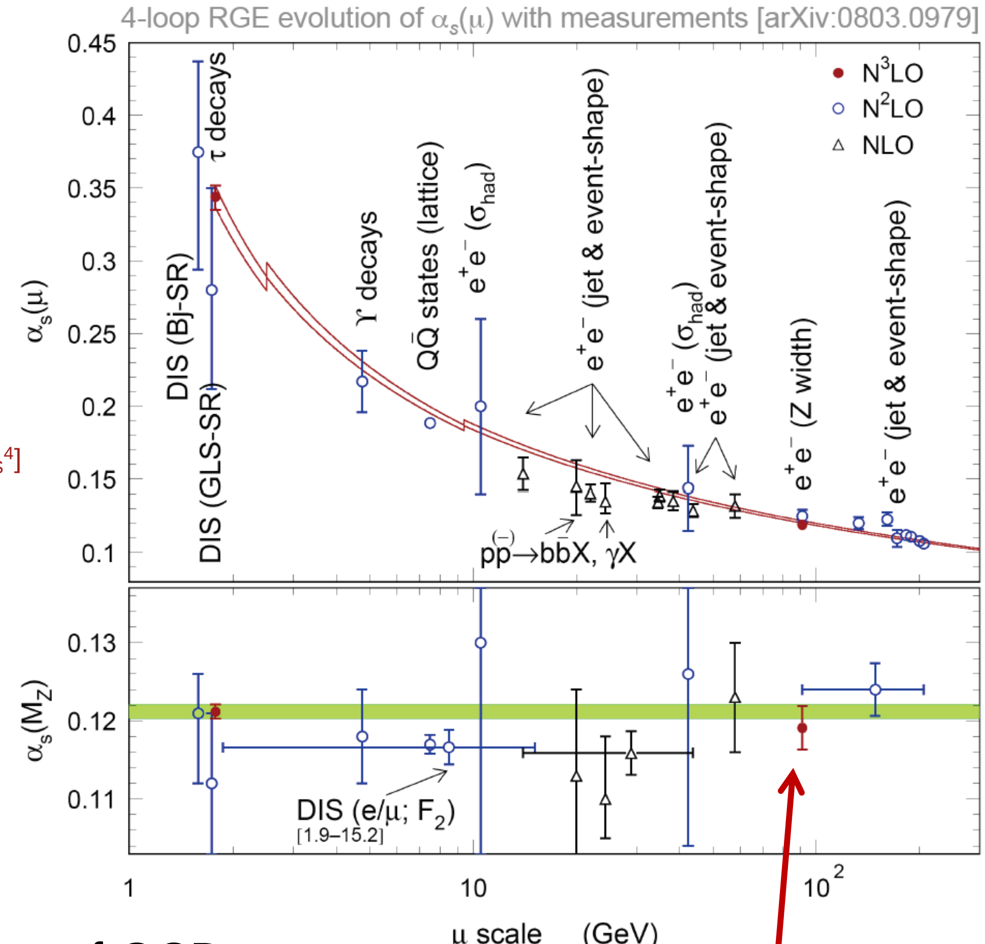
- first error experimental
- second error theoretical

  [incl. variation of renorm. scale from $M_Z/2$ to $2M_Z$ and massless terms of order/beyond α_S^5 and massive terms of order/beyond α_S^4]

- excellent agreement with N^3LO result from hadronic τ decays

  [M. Davier et al., arXiv:0803.0979]

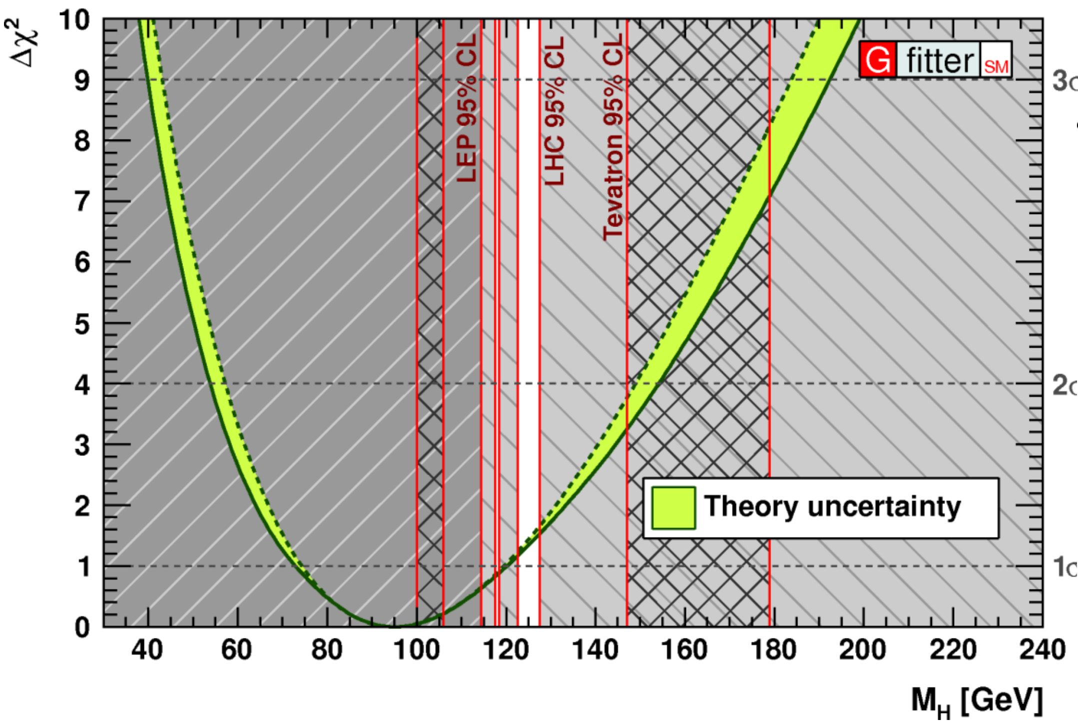
$$\alpha_s(M_Z^2) = 0.1212 \pm 0.0005_{exp}$$
$$\pm 0.0008_{theo} \pm 0.0005_{evol}$$

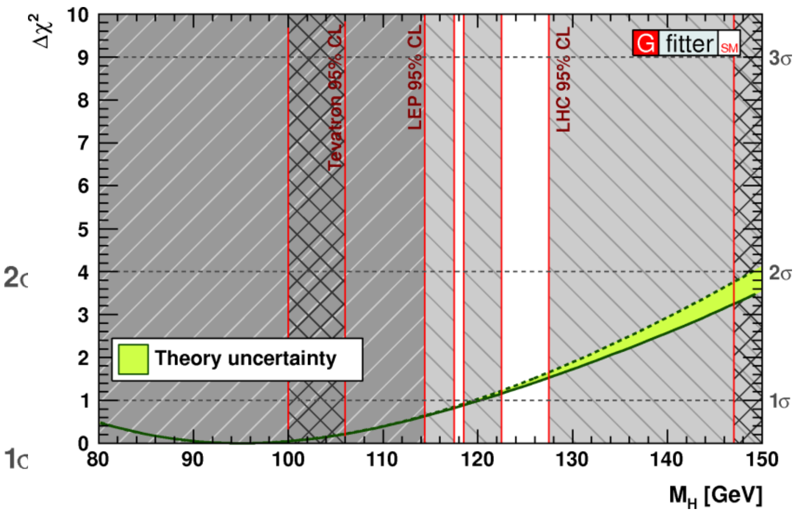


good test of asymptotic freedom property of QCD

old value: 0.1194 ± 0.0028

Higgs Mass Constraints





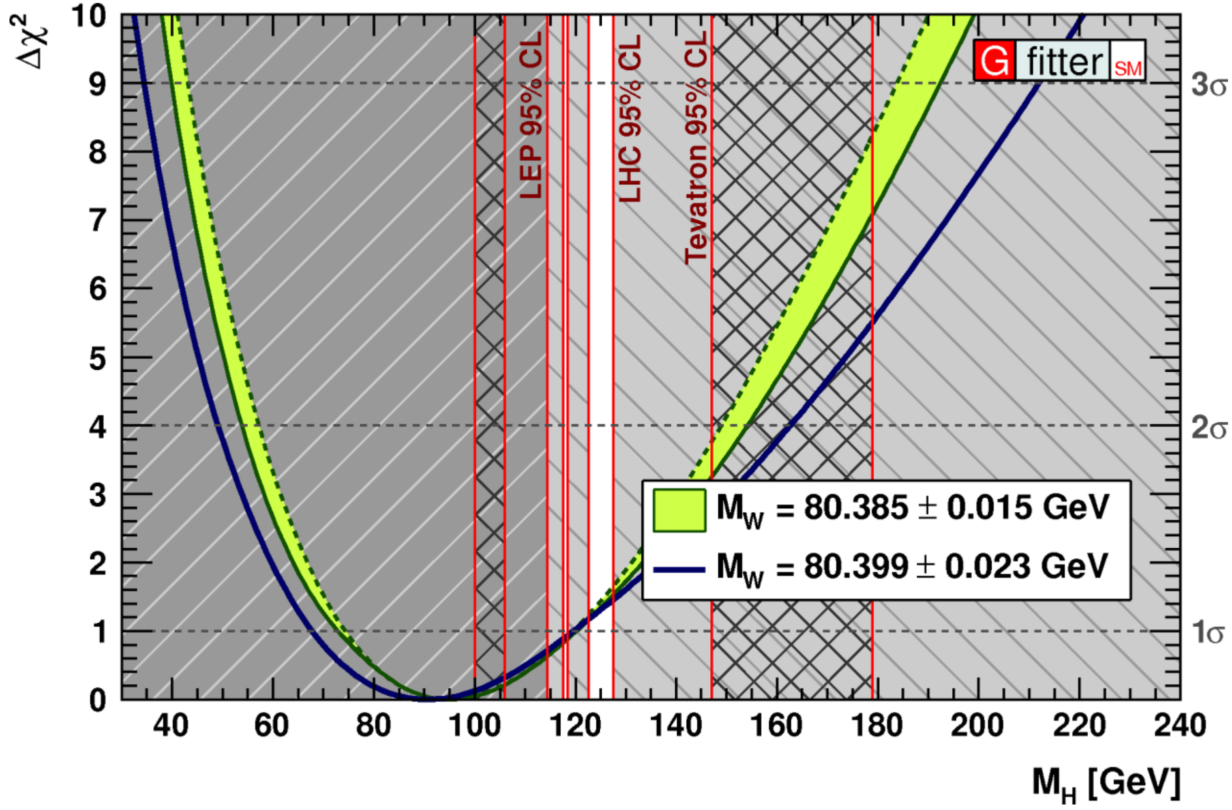
- value at minimum ±1σ:

$$M_H = 95^{+25}_{-22}\ \text{GeV}$$

- 95% CL upper bound 152 GeV
- 99% CL upper bound 176 GeV

- direct searches and indirect determination still in agreement
- in particular indirect result in agreement with Higgs boson at 125 GeV

Improvement from new W mass

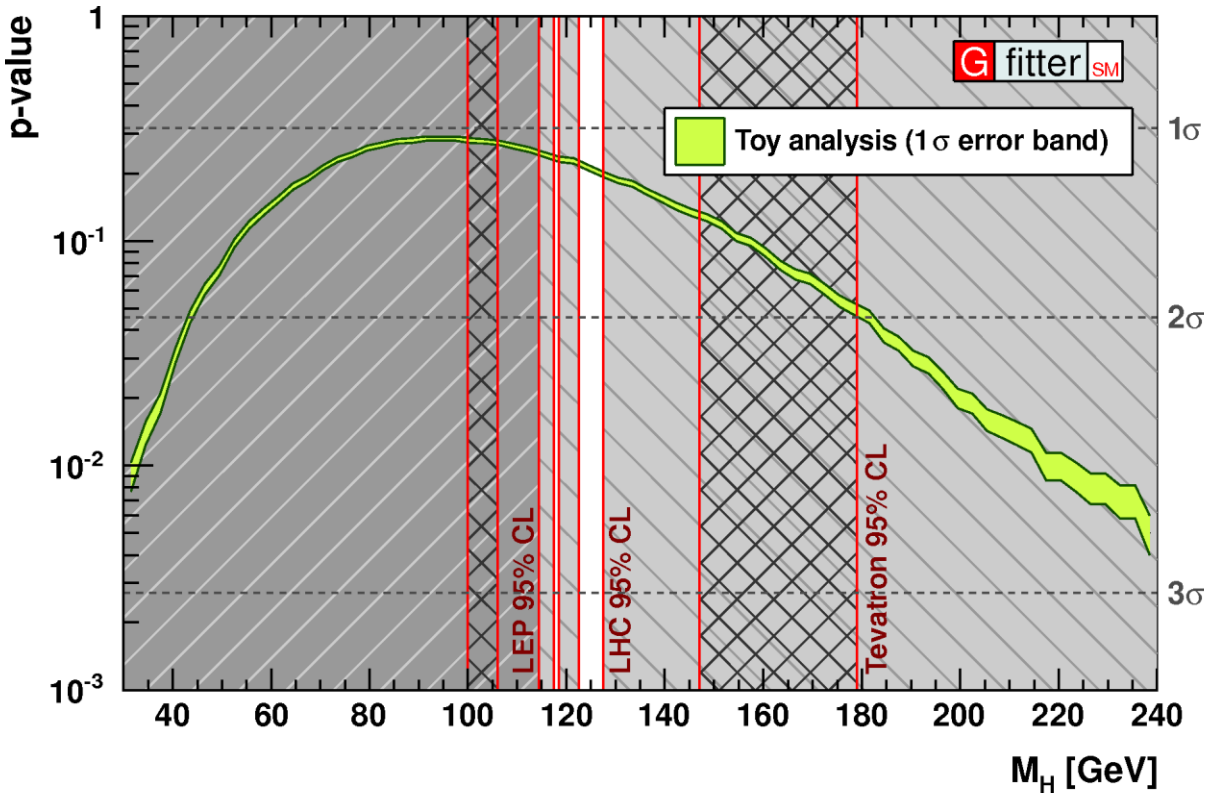


new W mass ➔ better 95% and 99% CL upper limits

➔ central value shifted to larger Higgs masses

p-Value versus Higgs Mass

- p-value: probability for wrongly rejecting the SM (probability for getting a $\chi^2_{min,toy}$ larger than the $\chi^2_{min,data}$ from data)
- p-value for fixed Higgs masses determined by using MC toy analysis
- allowed Higgs mass region ➔ reasonable p-value (~20%)

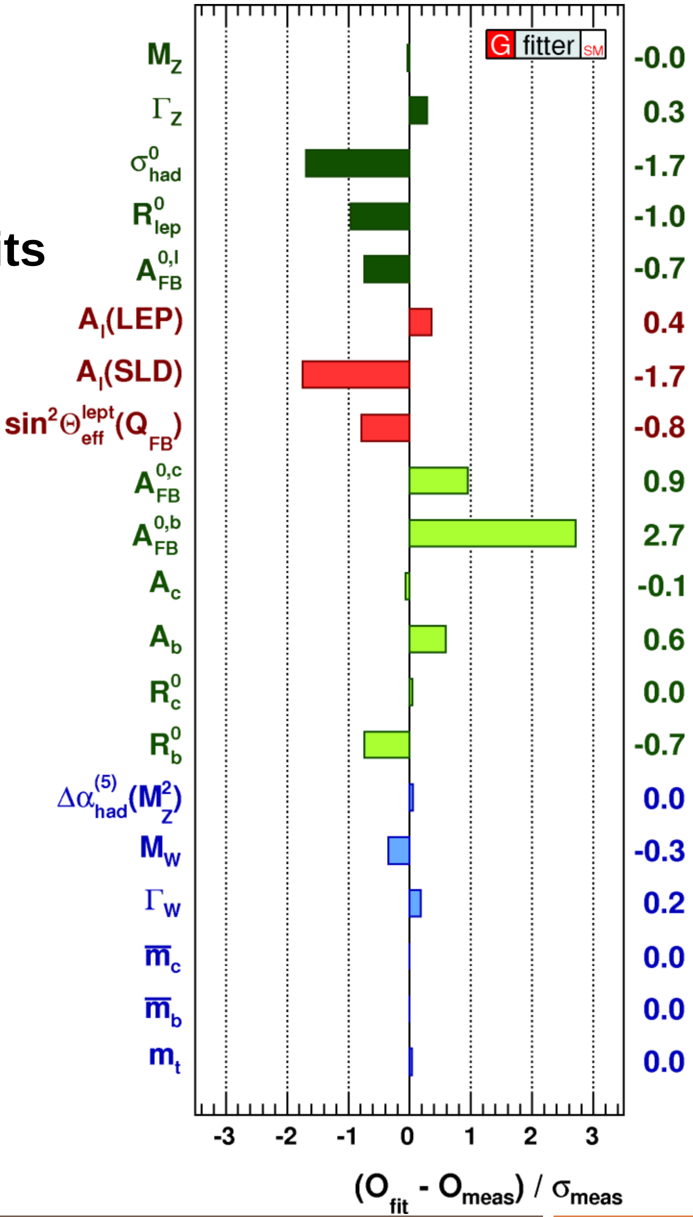


Goodness-of-Fit

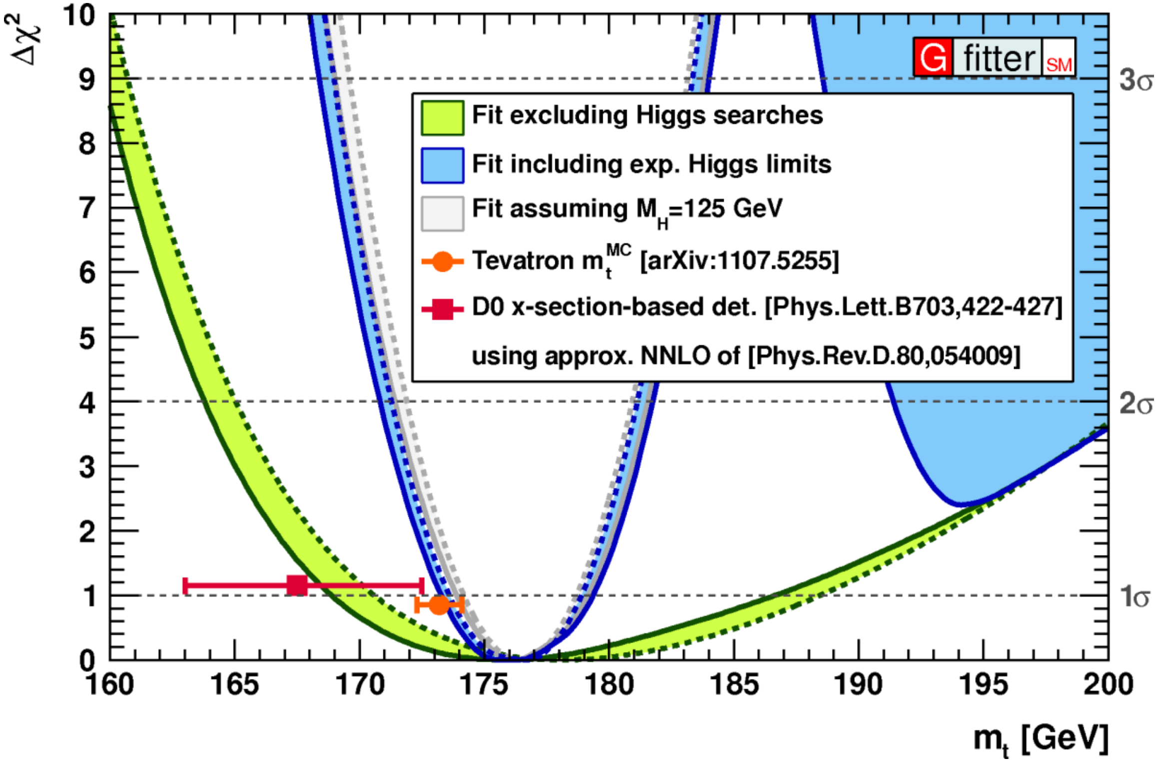
pull-values for the fit considering direct Higgs limits (Higgs mass take only values in allowed range)

- forward-backward asymmetry of bottom quarks → largest contribution to χ^2
- no value exceeds 3σ
- small contributions from M_Z, $\Delta\alpha_{had}^{(5)}$, charm and bottom mass indicate that their input accuracies exceed fit requirements

⇒ no significant requirement for new physics



Determination of Top Mass



w/o direct Higgs searches

$$m_t = 175.8^{+10.8}_{-6.9}\ \text{GeV}$$

considering Higgs limits

$$m_t = 175.6^{+3.8}_{-2.3}\ \text{GeV}$$

- indirect determination of top mass, *ie.* top mass measurement not included in the fit
- in agreement with direct Tevatron measurement (and D0 determination from top-pair cross-section [D0, Phys.Rev.D80,054009])

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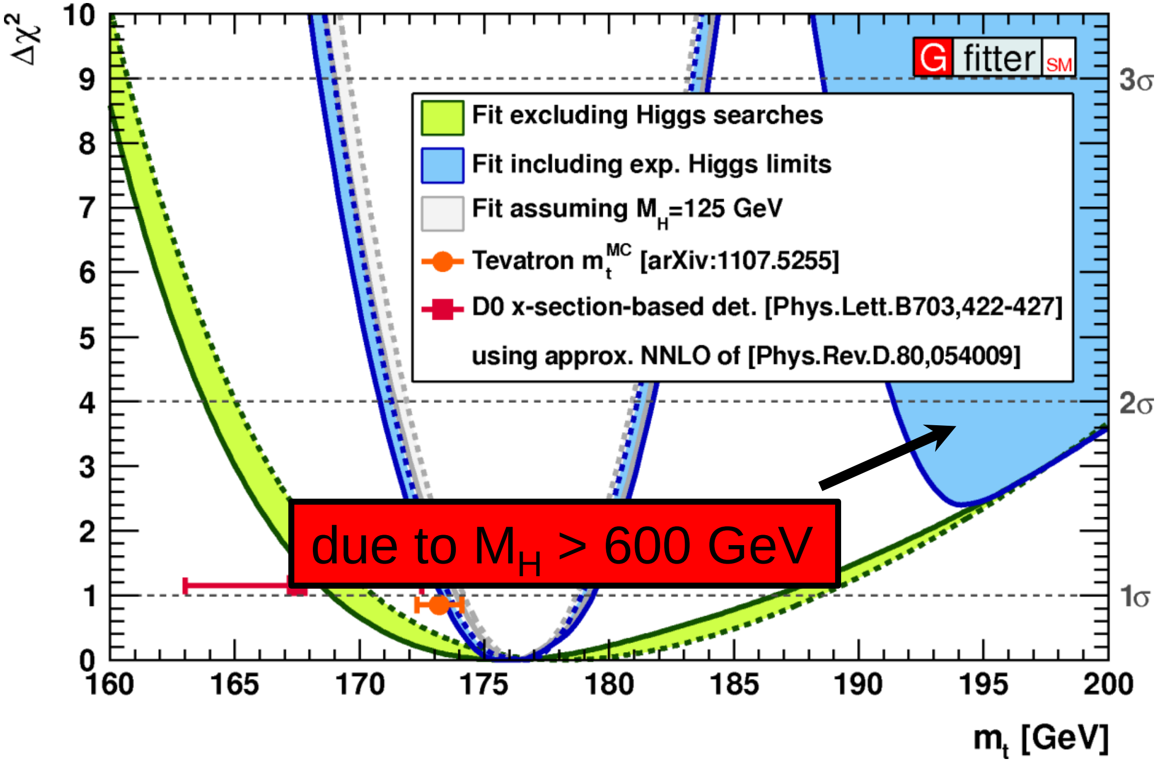

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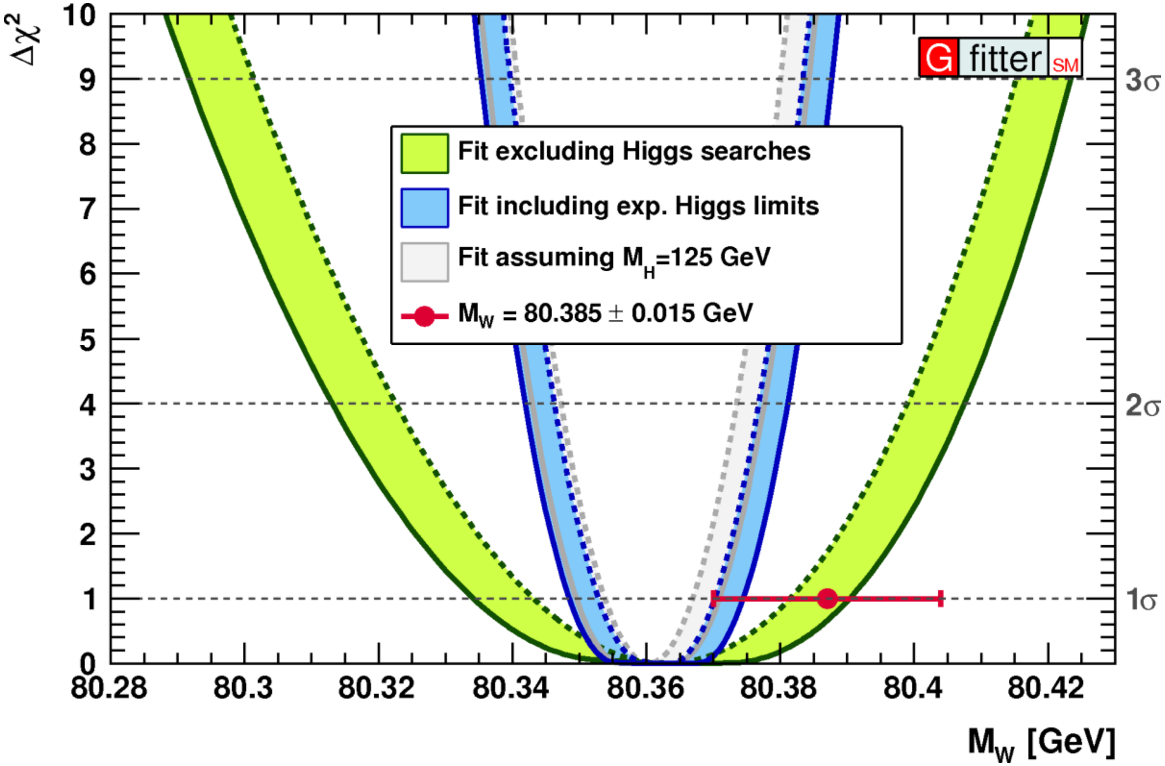
Determination of W Mass



w/o direct Higgs searches

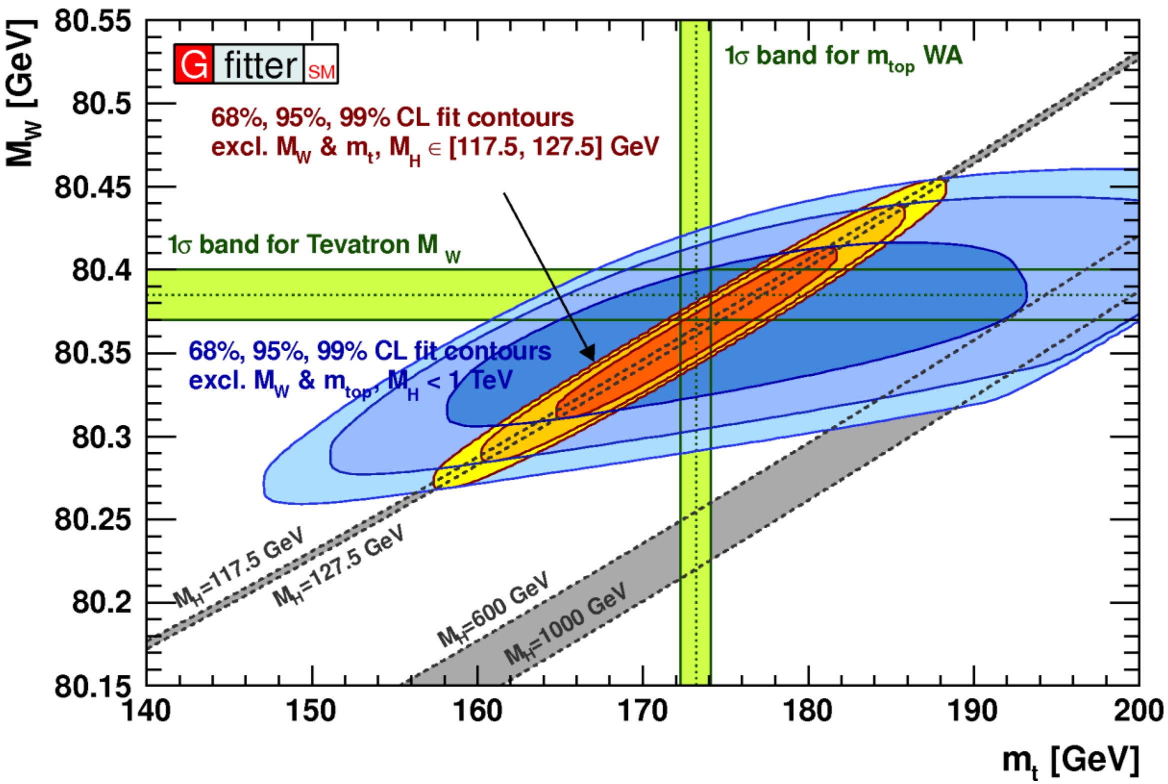
$$M_W = 80.366 \pm 0.028\,\text{GeV}$$

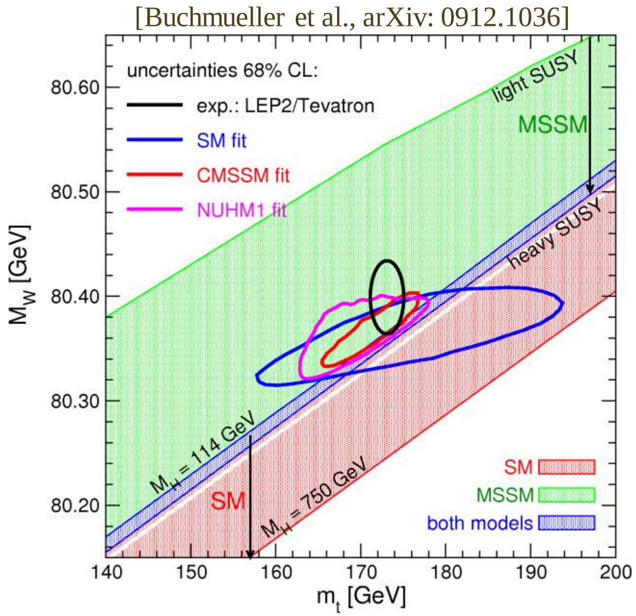
considering Higgs limits

$$M_W = 80.362^{+0.013}_{-0.012}\ \text{GeV}$$

- indirect determination of W mass, *ie.* no value for M_W is used in fits
- in agreement with world average of W mass
- indirect determination including direct Higgs constraints exceeds the precision of the world average

W and Top Mass

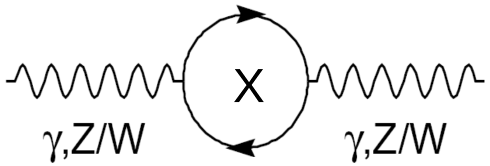




- indirect fit results agree with experimental values
- results from Higgs searches significantly reduce the allowed parameter space
- illustrative probe of SM (if M_H is measured at LHC and/or ILC)
- in addition good probe for new physics models (like SUSY)

Oblique Corrections

- physic beyond SM appear only through vacuum polarization

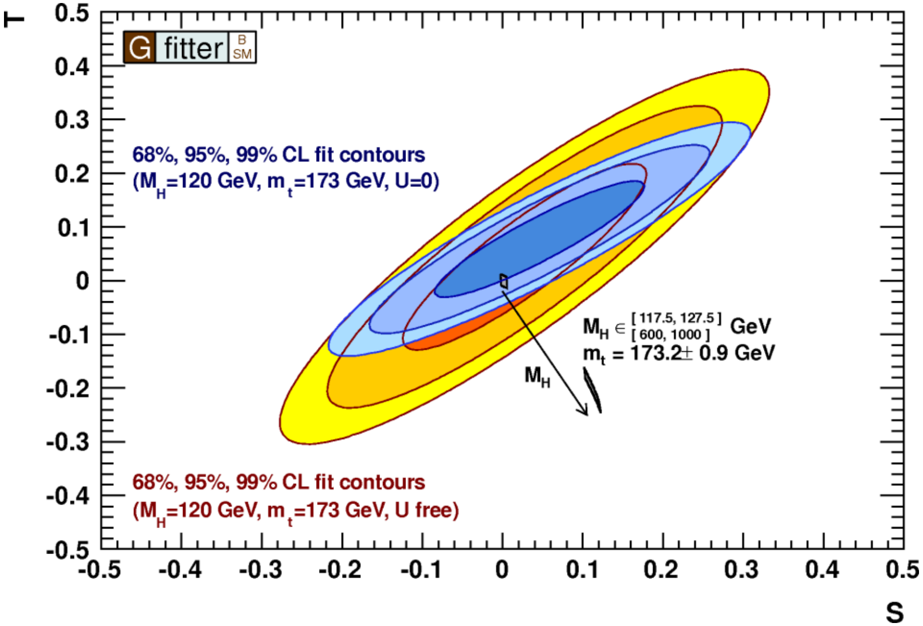


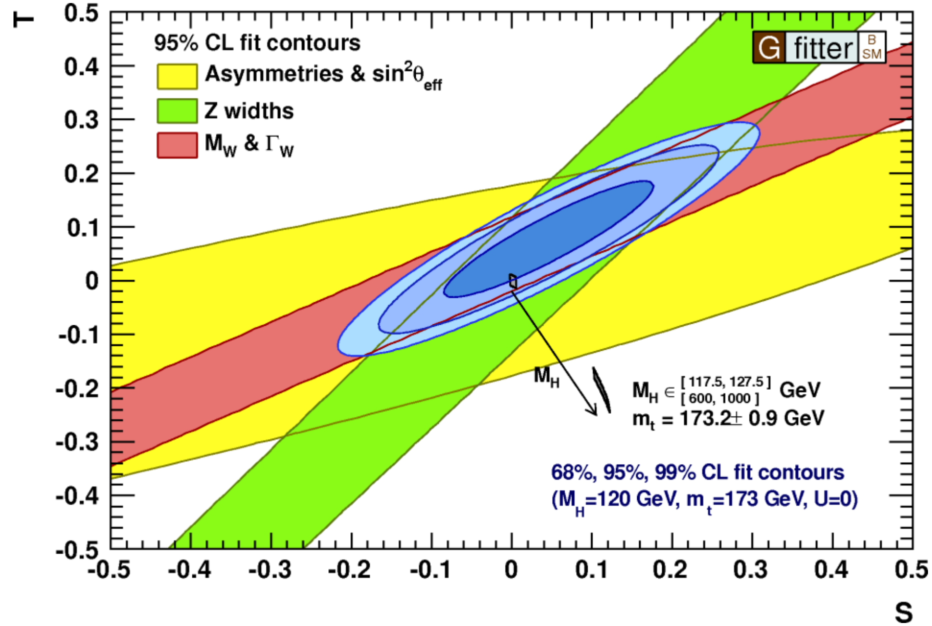
- two equivalent sets of parameters exist: ε and *STU* parameters
[Altarelli et al, Nucl. Phys. B405, 3 (1993)] [Peskin and Takeuchi, Phys. Rev. D46, 1 (1991)]
- SM predictions modified by parameterization of *STU* parameters
[Burgess, Pramana 45,S47 (1995)]
  - S: new physics contribution to neutral current
  - (S+U): new physics contribution to charged current
    - U only sensitive to W mass and width
    - usually very small in new physics models (often: U=0)
  - T: difference between neutral and charged current (sensitive to isospin violation)

$$O_{STU} = O_{SM}(M_{H,ref}, m_{t,ref}) + c_S S + c_T T + c_U U$$

  - depend on a (somewhat arbitrary) SM reference point
  - S=T=U=0 if data are equal to SM_{ref} prediction

Fit of STU Parameters

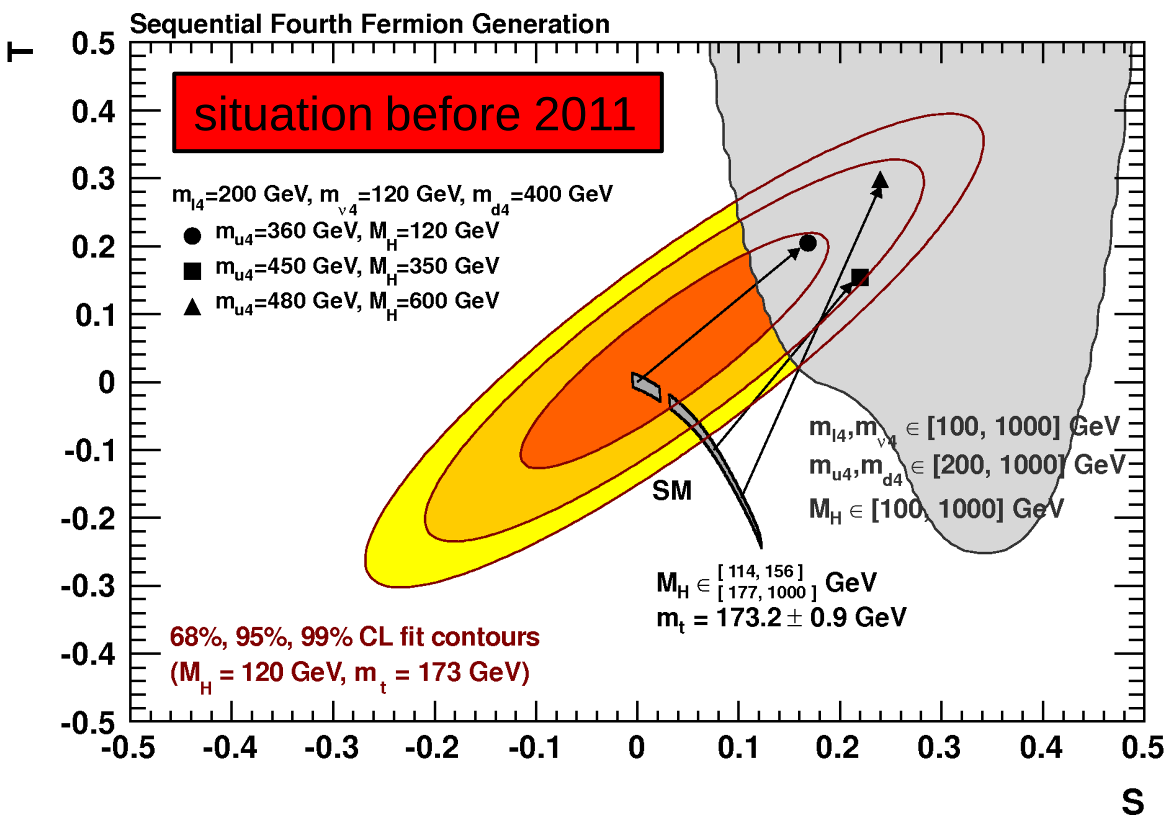




- derived from fit to electroweak precision observables
  (SM_{ref}: M_H=120 GeV, m_t=173 GeV)
- S = 0.03 ± 0.10, T = 0.05 ± 0.12, U = 0.03 ± 0.10 (with large correlation)
- *STU* values consistent with zero ➔ new physics contributions are small
- SM predictions (gray band) prefers small Higgs mass
- constraining new physics models by replacing *STU* parameters by their predictions in the new physics model

Sequential Fourth Generation

- oblique parameters mostly sensitive to mass difference of new generation
  [Phys.Rev.D64, 053004 (2001)]
- SM4: enhanced Higgs mass production ➔ Higgs masses excluded up to 600 GeV (some masses around 120 GeV still allowed)
  [CMS-PAS-HIG-12-008]



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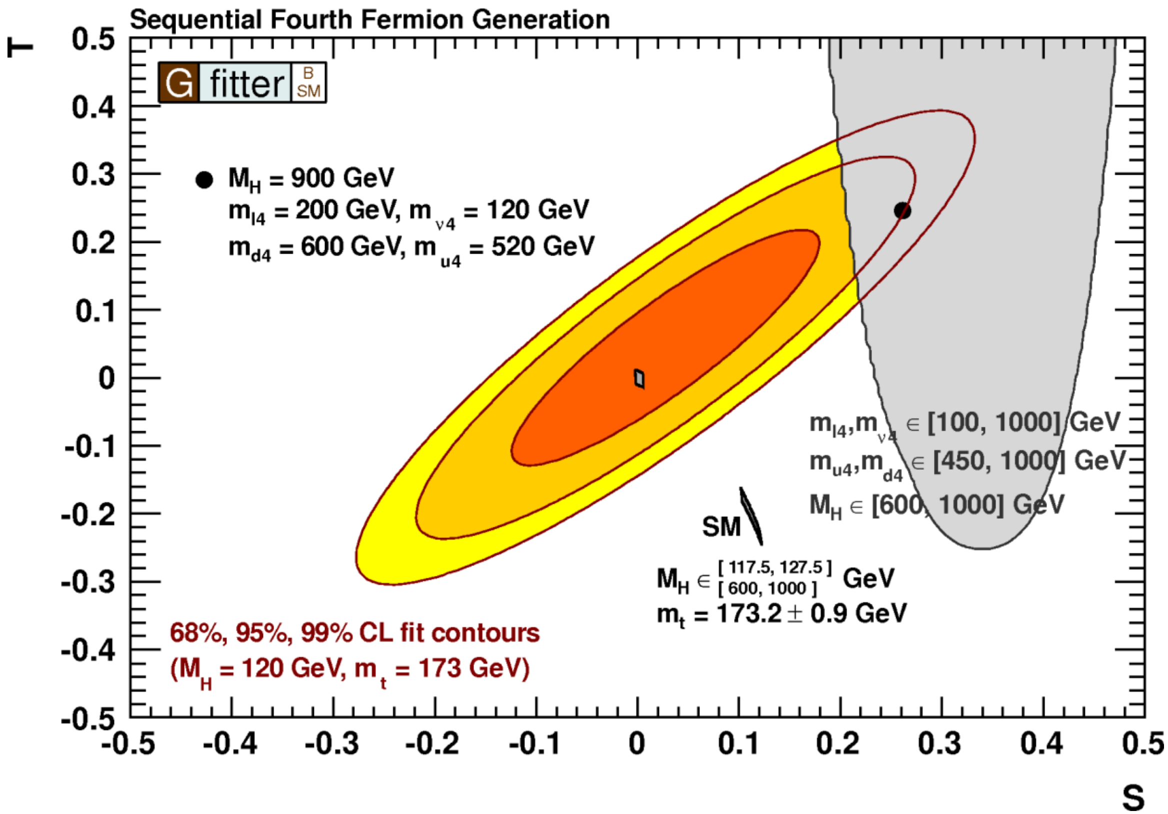

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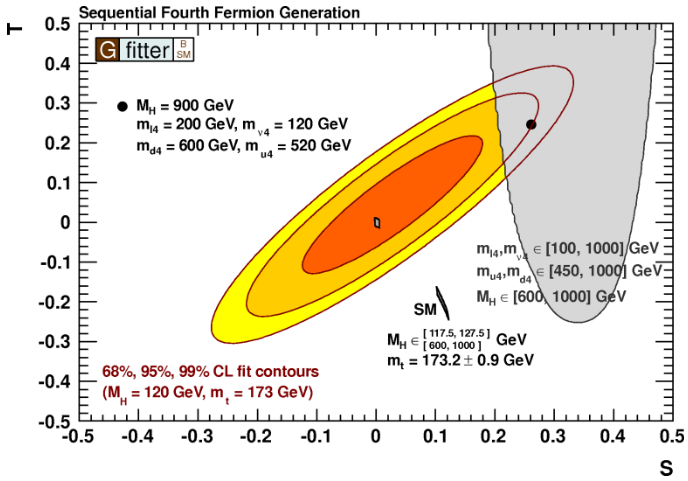
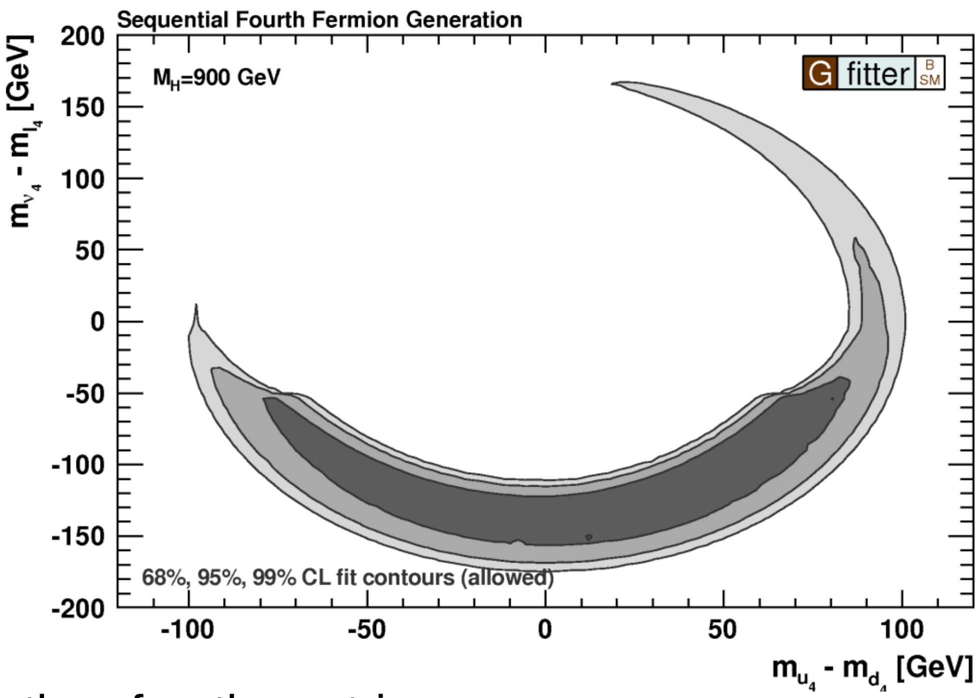
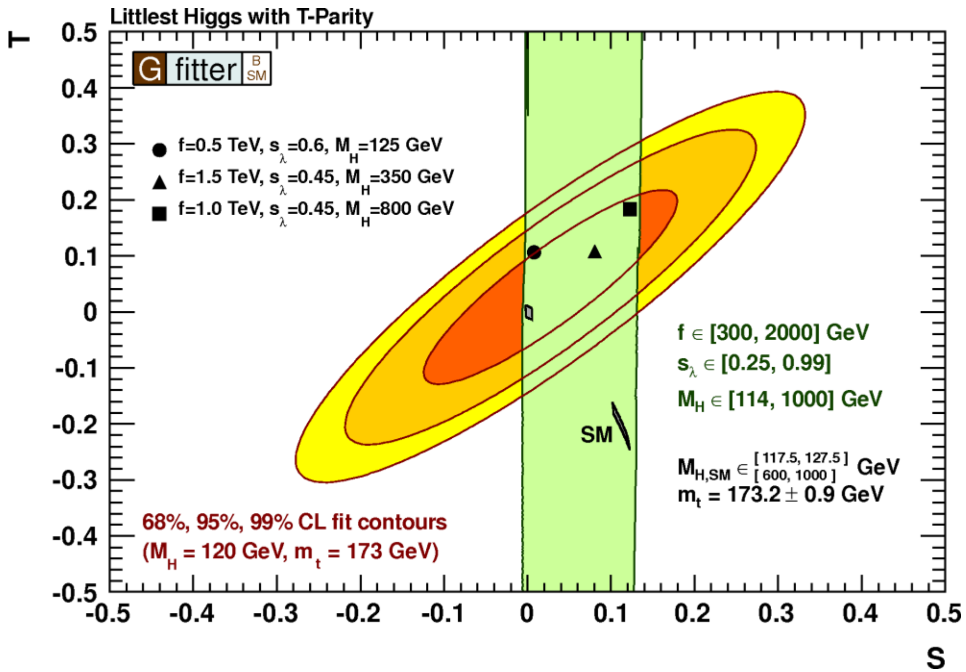




- fourth charged lepton heavier than fourth neutrino

Littlest Higgs Model with T-Parity

- Higgs pseudo-Nambu-Goldstone boson (gets its mass from multi-loop corrections)
  [Arkani-Hamed et al., JHEP 07, 034 (2002)]
- new fermions and new gauge bosons
  - two new top states (T-odd m_{T-} and T-even m_{T+})
  - LH solves hierarchy problem (new particles cancel SM loops)
- T-parity forbids tree-level contribution from heavy gauge bosons to SM observables
  [Cheng et al., JHEP 09, 051 (2003)] [Cheng et al., JHEP08, 061 (2004)]
- provide dark matter candidate
- parameters of LH model
  - f symmetry breaking scale (scale of new particles)
  - $s_\lambda \cong m_{T-} / m_{T+}$ ratio of masses in top sector
  - order one-coefficient d_c (exact value depends on detail of UV physics)
    - treated as theory uncertainty in fit (Rfit) δ_c=-5…5
- oblique parameters replaced by corrections from LH model
  [Hubisz et al., JHEP 0601:135 (2006)]

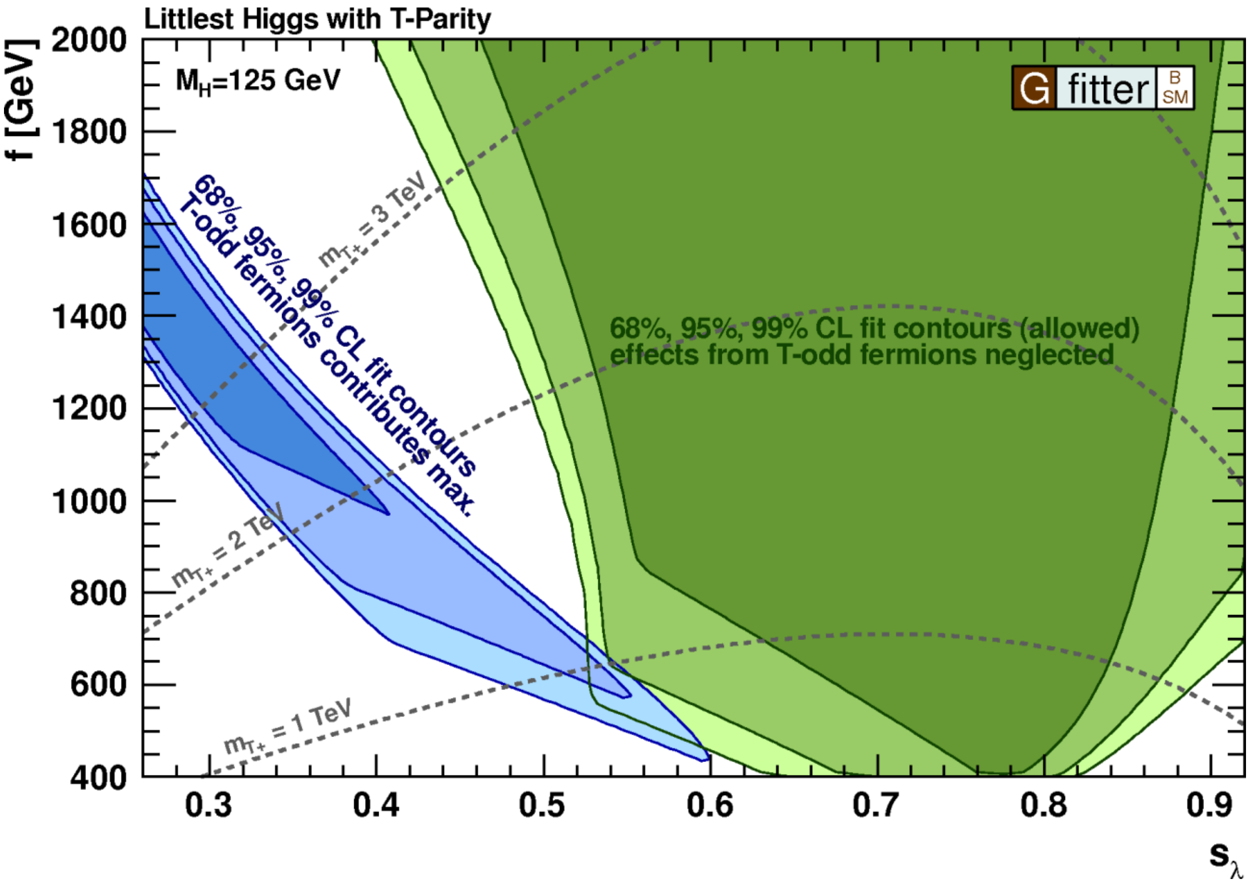


Higgs can also decay into invisible particles
➔ no direct Higgs limits used

S contribution rather small compared to T parameter

Littlest Higgs Model with T-Parity

- new T-even top state similar phenomenology SM top quark (e.g. $T_+ \rightarrow bW$, pair production and single production)
- T-odd top state produced in pairs (decay: $T_- \rightarrow tA_H$)



$$m_{T_+} = m_t \sqrt{\frac{1}{s_\lambda^2(1-s_\lambda^2)}} \frac{f}{v}$$

amount of fine-tuning rises with increasing f parameter (roughly)

Summary

Standard Model

- electroweak SM describes well the electroweak precision data
- indirect Higgs determination consistent with direct Higgs limits
- α_S from electroweak fit and τ-decays provide good test of the asymptotic freedom property of QCD

Physics beyond the Standard Model

- constraints from the electroweak precision data via the oblique parameters
- simple sequential fourth generation might have problems
- **but:** many other interesting models extending the three SM generations (e.g. littlest Higgs model with T-parity)